

# An ‘Intelligent Consultant’ – The Support for C2 System Operator When Fusing Ambiguous Information<sup>1</sup>

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## ABSTRACT

*The purpose of this paper is to present a concept of so called ‘intelligent consultant’ – that is a tool that provides C&C system operator a support in case the gathered information (acquired from observation means) is incomplete, imprecise or even conflicted.*

*It is the intention of the authors to focus on the methodological aspect of the problem which may be formed as: Does Dezert-Smarandache Theory (DSmT) of plausible and paradoxical reasoning enable to deal with difficult target classification which normally happens in maritime C&C systems. For this reason a comparison of hard-decision fusion, DSmT fusion and a combination of DSmT and ontology fusion algorithms has been established. Some numerical experiments have been made and their results have been delivered in this paper.*

## 1.0 INTRODUCTION

Nowadays, one of the most important requirements imposed on maritime C&C systems is a dealing with a problem of integrating information gathered from diverse sources (e.g. radars, video cameras and visual sightings). The diversity of sensors utilised for acquiring information, useful from the tactical point of view, implies a necessity of reconstruction of the situational awareness at the presence of concise information as well as at the presence of uncertain, incomplete or even conflicted information.

Experience in working with C&C systems shows that there are particular situations, where an indication of incoherent information (ambiguity or conflict) is caused by imprecise processing of information related to target attributes (e.g. target misclassification or attribute conversion errors). In these particular cases the most often step of the fusion algorithms is holding the combination process and an indication of the existing problem. If the number of targets grows, the probability of necessary manual intervention also rises, which in consequence may lead to a degradation of quality of the situational awareness.

An analysis of C&C systems operators’ needs shows that an automatic combination of attribute information is not enough requirement imposed on modern fusion systems. The fact the operator is responsible for the quality of elaborated information does not contradict with the idea of supporting

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him/her with the ‘intelligent consultant’ software which is to present the optimal solution, according to gathered imprecise and incomplete evidences.

The purpose of this paper is to present a concept and results of numerical experiments, related to the above mentioned intelligent consultant. This tool effectively utilises the relations among target attributes, defined in sensor network ontology [1]. A precise definitions of these relations have been given using elements of Dezert-Smarandache Theory [2], [3].

### 2.0 COMBINATION OF ONTOLOGIES AND DSMT

This section presents a proposition of an ontology framework for a sensor network, dedicated to monitor the target threat. In the solution there were utilised concepts and concept lexicons of JC3 model [4]. The authors’ intention was to show the way relations of three attributes (threat, platform and activity) should be defined, rather than to present the complete SN ontology.

Table 1 presents a bijective assignment of concepts to elements of a concept lexicon. As it was mentioned before, this assignment need not be a bijection, however it is desirable especially if sets of values for attributes of platform and activity are numerous.

**Table 1: SN ontology: concepts and concept lexicon.**

<b>Concepts</b>		<b>Concept lexicon</b>	
<b>Threat</b>	An OBJECT-ITEM that is assumed to be a friend because of its characteristics, behaviour or origin.	<i>object-item-hostility-status-code</i>	ASSUMED FRIEND
	An OBJECT-ITEM that is positively identified as enemy.		HOSTILE
	...according to JC3		... according to JC3
<b>Platform</b>	General designator for aircraft/multi-role aircraft carrier;	<i>surface-vessel-type-category-code</i>	AIRCRAFT CARRIER, GENERAL
	Craft 40 meters or less employed to transport sick/wounded and/or medical personnel.		AMBULANCE BOAT
	... according to JC3		... according to JC3
<b>Activity</b>	To fly over an area, monitor and, where necessary, destroy hostile aircraft, as well as protect friendly shipping in the vicinity of the objective area.	<i>action-task-activity-code</i>	PATROL, MARITIME
	Emplacement or deployment of one or more mines.		MINE-LAYING
	... according to JC3		... according to JC3

The assignment of relations among attributes to relation lexicons (Table 2) is a surjection. In order to define the relations among attributes *DSmT* combining and conditioning rules have been applied. The preferred rule for conditioning is the rule no. 12. When combining evidence, there is a possibility to use many combination rules, depending the particular relation. However, for simplicity, it is suggested to apply the classic rule of combination (*DSmC*), which has properties of commutativity and associativity.

**Table 2: SN ontology: relations and relation lexicon.**

<b>Relations</b>		<b>Remarks</b>	<b>Relation lexicon</b>
<b>Rel. I:</b>	<i>cond(.)</i>	Based on <i>DSmT</i>	<i>Conditioning</i>
	→	According to distinctive features	<i>Implication</i>
<b>Rel. II:</b>	<i>cond(.)</i>	Based on <i>DSmT</i>	<i>Conditioning</i>
	⊕	Based on <i>DSmT</i>	<i>Combination</i>
<b>Rel. III:</b>	<i>cond(.)</i>	Based on <i>DSmT</i>	<i>Conditioning</i>
	⊕	Based on <i>DSmT</i> (combination rule need not be identical with one in Relations II)	<i>Combination</i>

Below, there have been presented examples of particular types of relations. In case of the relation of type I it is possible to reason about a value of a certain attribute, based on the knowledge about the other ones. However, if the unambiguous deduction of the third attribute is not possible, due to the majority of possible solutions, an application of abductive reasoning (selection of the optimal variant) seems to be justified.

Relations I:

(*Threat, Platform*) → *Activity*: (*FAKER, FRIGATE TRAINING*) → *TRAIN OPERATIONS*;  
 (*Threat, Activity*) → *Platform*: (*FAKER, TRAIN OPERATIONS*) → *TRAINING CRAFT*;  
 (*Platform, Activity*) → *Threat*: (*HOUSEBOAT, PROVIDE CAMPS*) → *NEUTRAL*;

Relations II:

*FAKER* = *cond(obs(FAKER))* ⊕ *ded(FAKER)* ⊕ *obs(FRIEND)*;

Relations III:

*FAKER* = *cond(obs(FAKER))* ⊕ *VS(FAKER)* ⊕ *IFF(FRIEND)*;

The abductive reasoning process may be systemized by application of *DSmT*, where the selection of the optimal value takes place after calculating the basic belief assignment.

Example 3:

(*Threat, Activity*) → *Platform*: (*FRIEND, MINE HUNTING MARITIME*) →  
*MINEHUNTER COASTAL (MHC)* ∨ *MINEHUNTER COASTAL WITH DRONE (MHCD)* ∨  
*MINEHUNTER GENERAL (MH)* ∨ *MINEHUNTER INSHORE (MHI)* ∨  
*MINEHUNTER OCEAN (MHO)* ∨ *MINEHUNTER/SWEEPER COASTAL (MHSC)* ∨  
*MINEHUNTER/SWEEPER GENERAL (MHS)* ∨ *MINEHUNTER/SWEEPER OCEAN (MHSO)* ∨  
*MINEHUNTER/SWEEPER W/DRONE (MHSD)*

Applying *DSmT*, for each of possible hypothesis a certain mass of belief is assigned, e.g.:

$$m(MHC) = 0.2, m(MHCD) = 0.3, m(MH) = 0.1, m(MHI) = 0.1, m(MHO) = 0.1, \\ m(MHSC) = 0.05, m(MHS) = 0.05, m(MHSO) = 0.05, m(MHSD) = 0.05$$

Based on the obtained *basic belief assignment (bba)* belief functions, referring to particular hypotheses, may be calculated. In the simplest case, assuming all of the hypotheses are exclusive, the subsequent belief functions will be equal to respective masses, e.g. *Bel(MHC) = m(MHC)*, *Bel(MHCD) = m(MHCD)*, etc.

### 3.0 EXPERIMENTS ASSUMPTIONS

A relevance examination of the reconstructed attribute information of the manoeuvring target has been made in Matlab environment. Reconstruction was related to the following target attributes:

- Target threat;
- Target platform;
- Target activity.

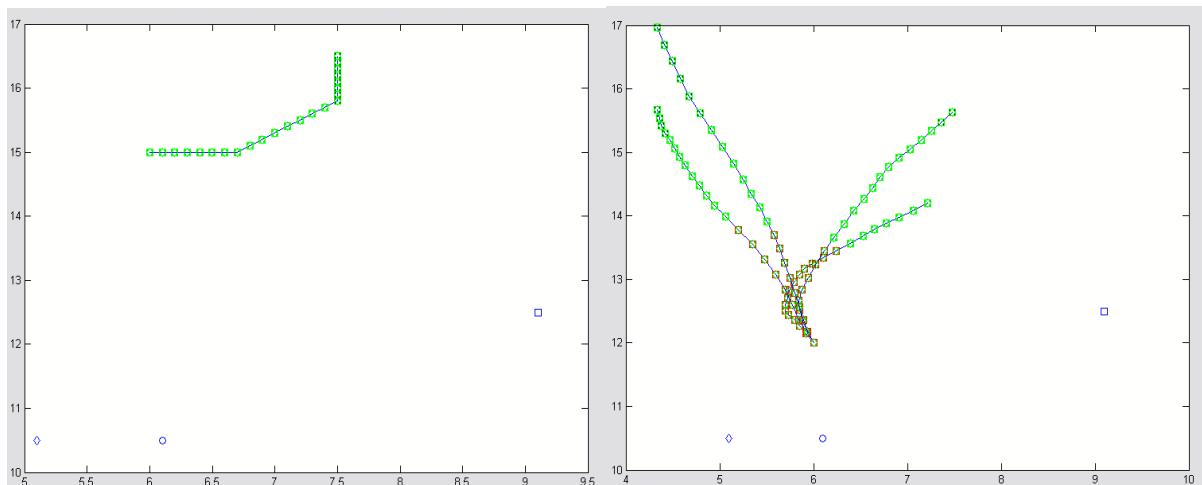
The proposed sensor network enables the attribute information reconstruction based on:

- observation as well as
- reasoning process.

#### 3.1 Simulation of the target’s motion

For the purpose of the experimentation it is considered the target trajectory may be generated:

- deterministically, as show at Figure 1 as well as
- randomly, according to normal distribution of modifiable parameters.



**Figure 1: Simulated target trajectories (deterministic - on the left, and random - on the right).**

Kinematic parameters of the target are not considered. Therefore the above mentioned assumptions seem to be adequate for the experimentation since the varying target to source distance, that influences the observation quality, is modelled.

#### 3.2 Sensor network organisation assumptions

For simplicity it is assumed the considered sensor network consists of three sensors each of which enables to acquire information about target threat, target platform and target activity. Due to the fact that the experimentation is based on simulations no requirements related to a physical topology of the sensor network have been defined. A logical topology is assumed to be of tree type. This results directly from the dynamic fusion since the selected combination rule has been defined for two sources.

It is worth of notice that the assumption that each sensor enables to gain information about each of the considered attributes may be regarded as each of the sensors performs a subnet of fully connected sensors. In case of *DSmT* ontology fuser interactions among particular attributes are considered.

### 3.3 Information fusion assumptions

Three fusion algorithms have been put to the examination:

- Hard-decision fusion with *Majority Rule (MR)* [5], implemented, separately for each of the attributes;
- *DSmT* fusion based on the hybrid combination rule
- Ontology-based *DSmT*, where the interaction among attributes is performed according to *Belief Conditioning Rule no. 1 (BCR1)*.

### 3.4 Sensor network ontology assumptions

For simplicity it is assumed:

- Concept lexicon for the threat attribute is compatible with *Link-16* [6], (partially compatible with *JC3*);
- Concept lexicon for the platform attribute *surface-vessel-type-category-code* of *JC3* model is constrained to mine warfare vessels;
- Concept lexicon for the activity attribute is defined by the authors, consisting of the most representative (in the authors’ opinion) values;

Another assumptions are formed for so called ontology fusion.

- Interaction among attributes is performed with respect to belief conditioning rules (according to *DSmT*).
- Possible influences are defined as:
  - single attribute to another single attribute;
  - single attribute to another many attributes;
  - many attributes to another many attributes.

## 4.0 EVALUATION OF INFORMATION IN SENSOR NETWORK

Information evaluation is performed in two stages [7]:

- Information source evaluation: (0-1), where 1- indicates the ideal source;
- Evaluation of the degree of belief in particular hypotheses - defining basic belief assignment (*bba*);

For the threat attribute the following features are under assessment:

- Hostile/friend classification;
- Hostile/unknown classification (the degree of confidence the target is hostile);
- Unknown/friend classification (the degree of confidence the target is friendly);

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For the platform attribute the following features are under assessment:

- Mine-hunter/minesweeper classification;
- Oceanic/coastal classification;
- Equipped with drone/not equipped with drone classification;

For the activity attribute the following features are under assessment:

- Military/non-military classification;
- Training/real classification;
- Assault/defence classification;

The example of the resulting assessment of target threat attribute (threat bba) is shown at Figure 2.

		Threat:								
		HOS	UNK	NEU	JOK	FRD	FAK	SUS	AFR	PEN
Sensor1:		0.3141	0.0004	0.0001	0.0010	0.0003	0.0004	0.0034	0.0004	0.6800
Sensor1:		0.3134	0.0005	0.0001	0.0012	0.0003	0.0004	0.0035	0.0004	0.6800
Sensor1:		0.3147	0.0004	0.0001	0.0009	0.0002	0.0003	0.0031	0.0003	0.6800
Sensor1:		0.3123	0.0006	0.0002	0.0015	0.0004	0.0005	0.0040	0.0005	0.6800
Sensor1:		0.2998	0.0015	0.0004	0.0034	0.0009	0.0012	0.0115	0.0012	0.6800
Sensor 2:		HOS	UNK	NEU	FRD	FAK	SUS	AFR	PEN	
Sensor 2:		0.4110	0.0003	0.0001	0.0002	0.0003	0.0027	0.0003	0.5852	
Sensor 2:		0.1902	0.0129	0.0031	0.0078	0.0100	0.0702	0.0114	0.6943	
Sensor 2:		0.2277	0.0004	0.0001	0.0003	0.0004	0.0033	0.0003	0.7675	
Sensor 2:		0.1483	0.0024	0.0008	0.0017	0.0025	0.0256	0.0022	0.8165	
Sensor 2:		0.1142	0.0018	0.0006	0.0013	0.0017	0.0113	0.0016	0.8674	
Sensor 3:		HOS	FRD	FAK	SUS	AFR	PEN			
Sensor 3:		0.6760	0.0014	0.0019	0.0189	0.0018	0.3000			
Sensor 3:		0.6855	0.0009	0.0012	0.0112	0.0012	0.3000			
Sensor 3:		0.6644	0.0018	0.0024	0.0289	0.0025	0.3000			
Sensor 3:		0.6569	0.0031	0.0042	0.0318	0.0040	0.3000			
Sensor 3:		0.6695	0.0017	0.0023	0.0243	0.0022	0.3000			

Figure 2: Bba for the threat attribute based on the sensor-originated information respectively: visual sightings, video camera and radar.

## 5.0 INFORMATION FUSION IN SENSOR NETWORK

The hard-decision fusion is realised with *majority rule (MR)* implemented. It is assumed the *MR* algorithm is supplied with data from *the evaluator*<sup>2</sup>, which means that as well as the primary hypotheses, the secondary hypotheses (made with union and intersection operations) are to be utilised. The degree of knowledge about the target is specified according to the following formula:

$$K = 1 - (1 - P_{\max}^I)(1 - P_{\max}^{II}) \quad (1)$$

The *DSmT* fusion is realised with the hybrid rule of combination. The respective frames of discernment are defined as follows:

$$\Theta_{Tk} = \{HOS, UNK, FRD, NEU\} \quad (2)$$

<sup>2</sup> Block of the information processing scheme, where the evaluation of information is performed, according to the rules described in section 4.

$$\Theta_{Pla} = \{MHC, MHI, MHO, MSC, MSO, D\} \quad (3)$$

$$\Theta_{Act} = \{ATC, MINE, UNK, FISH, DN\} \quad (4)$$

For each attribute the separate fusion process is performed. The resulting characteristics decision is a superposition of partial decisions, related to each of the attributes. The degree of knowledge about the target is specified in accordance to the belief function value of the accepted hypothesis.

The ontology *DSmT* fusion effectively utilises the additional information about some of the attributes based on the decisions made previously. For instance: (*Threat, Activity*) → *Platform*. In order to do that a *conditioning* operation is performed. For the numerical experiments the *BCR1* has been used. In case the particular decision implicates several values of another attribute the condition is defined as an alternative of these values. For example:

$$\begin{aligned}
 (FRIEND, MINE HUNTING MARITIME) \rightarrow & \quad MINEHUNTER COASTAL (MHC) \vee \\
 & MINEHUNTER COASTAL WITH DRONE (MHCD) \vee \\
 & MINEHUNTER GENERAL (MH) \vee \\
 & MINEHUNTER INSHORE (MHI) \vee \\
 & MINEHUNTER OCEAN (MHO) \vee \\
 & MINEHUNTER/SWEEPER COASTAL (MHSC) \vee \\
 & MINEHUNTER/SWEEPER GENERAL (MHS) \vee \\
 & MINEHUNTER/SWEEPER OCEAN (MHSO) \vee \\
 & MINEHUNTER/SWEEPER W/DRONE (MHSD)
 \end{aligned}$$

The conditioning operation is usually used in *DSmT* for updating bba, based on some objective facts (theses), on the contrary to the *combination* (fusion), where bba is augmented with a new uncertain (subjective, by definition) evidence. In the considered case the goal is to achieve the coherent information about the target. Thus, the decisions made regarding one attribute may be treated as quasi-objective and used for ‘homing’ the decisions (made by combination) related to another attribute.

This operation enables to obtain more concise target model consuming the same pieces of information and constrain the uncertainty while decision-making, comparing to the rest of the considered fusion techniques.

## 6.0 SENSOR NETWORK ONTOLOGY

The attribute relation G functions has been defined as follows:

$$\begin{cases} G_{Thr}(pla, act) = Cond(Thr, \{pla, act\}) \\ G_{Pla}(thr, act) = Cond(Pla, \{thr, act\}) \\ G_{Act}(thr, pla) = Cond(Act, \{thr, pla\}) \end{cases} \quad (5)$$

where:

*Thr*<sup>3</sup>, *thr* – target threat;

*Pla*, *pla* – target platform;

*Act*, *act* – target activity;

---

<sup>3</sup> The following distinction is introduced to distinguish resulting attributes (capital letters) from arguments of conditioning functions (small letters).

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All possible implications among attributes are defined in so called implication tables. These tables perform the deterministic base of the relations among attributes. For the purpose of the experimentation these tables have been determined by logic only, however their modification is possible if any additional (e.g. mine-warfare or SAR<sup>4</sup> domains) expert knowledge appears. According to assumed implication tables possible implications are listed below:

$$\begin{aligned}
 G : & \begin{array}{l} \text{Thr} \rightarrow \text{Pla} \\ \text{Thr} \rightarrow \text{Act} \\ \text{Pla} \rightarrow \text{Thr} \\ \text{Pla} \rightarrow \text{Act} \\ \text{Act} \rightarrow \text{Thr} \\ \text{Act} \rightarrow \text{Pla} \\ \text{Thr} \rightarrow \text{Pla} \rightarrow \text{Act} \\ \text{Thr} \rightarrow \text{Act} \rightarrow \text{Pla} \\ \text{Pla} \rightarrow \text{Thr} \rightarrow \text{Act} \\ \text{Pla} \rightarrow \text{Act} \rightarrow \text{Thr} \\ \text{Act} \rightarrow \text{Pla} \rightarrow \text{Thr} \\ \text{Act} \rightarrow \text{Thr} \rightarrow \text{Pla} \\ \text{Thr}, \text{Pla} \rightarrow \text{Act} \\ \text{Thr}, \text{Act} \rightarrow \text{Pla} \\ \text{Pla}, \text{Act} \rightarrow \text{Thr} \end{array} \tag{6}
 \end{aligned}$$

Based on the implication tables, due to the selected conditioning rule bba may be updated. Thus the resulting bba becomes conditioned according to *DSmT*, without disturbing its random nature (see [3]).

## 7.0 VISUALISATION OF SENSOR NETWORK RESULTS

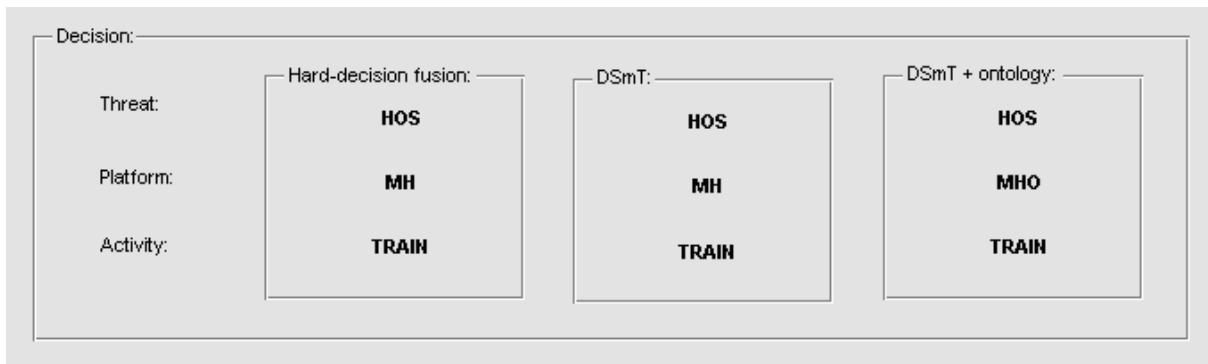
Basic belief assignment (bba) for each of the sensors performs the middle result of sensor network. It summarises an assessment of each of possible hypotheses. Based on these particular bbas the resulting bba is calculated and next belief function values for each of the hypotheses necessary for decision-making.

Information evaluation																											
Sensor:	Threat:					Platform:					Activity:																
	HOS	UNK	NEU	JOK	FRD	FAK	SUS	AFR	PEN	MHD	MH	MHSO	MHSD	MHS	MHC	MHI	MHO	PEN	TRAIN	UNK	MNE	ATK	PATR	FISH	NOT	BOR	PEN
Sensor 1:	0.3177	0.0002	0.0007	0.0006	0.0003	0.0002	0.0003	0.0002	0.0001	0.0457	0.0434	0.0617	0.0320	0.0286	0.0391	0.0248	0.0348	0.0800	0.3022	0.0015	0.0005	0.0040	0.0010	0.0089	0.0009	0.0009	0.6800
	0.3151	0.0003	0.0009	0.0002	0.0002	0.0027	0.0003	0.0003	0.0001	0.0457	0.0434	0.0617	0.0320	0.0286	0.0391	0.0248	0.0348	0.0800	0.3137	0.0002	0.0001	0.0005	0.0001	0.0015	0.0002	0.0002	0.6835
	0.3137	0.0002	0.0001	0.0005	0.0001	0.0002	0.0015	0.0002	0.0001	0.0452	0.0429	0.0610	0.0316	0.0283	0.0386	0.0244	0.0344	0.0800	0.3010	0.0007	0.0002	0.0014	0.0007	0.0059	0.0004	0.0004	0.6894
	0.3010	0.0007	0.0002	0.0014	0.0005	0.0007	0.0050	0.0007	0.0001	0.0443	0.0421	0.0599	0.0310	0.0277	0.0379	0.0238	0.0338	0.0800	0.2977	0.0005	0.0002	0.0014	0.0005	0.0038	0.0005	0.0005	0.6951
	0.2977	0.0005	0.0002	0.0014	0.0004	0.0005	0.0038	0.0005	0.0001	0.0435	0.0414	0.0588	0.0305	0.0274	0.0372	0.0232	0.0332	0.0800	0.3110	0.0004	0.0001	0.0011	0.0003	0.0003	0.0003	0.0003	0.6835
Sensor 2:	0.4133	0.0031	0.0082	0.0022	0.0028	0.0175	0.028	0.0500	0.0001	0.0712	0.1012	0.0524	0.0469	0.0641	0.0571	0.0571	0.0500	0.4233	0.0018	0.0047	0.0011	0.0015	0.0160	0.0166	0.0500	0.0001	
	0.4133	0.0031	0.0082	0.0022	0.0028	0.0175	0.028	0.0500	0.0001	0.0712	0.1012	0.0524	0.0469	0.0641	0.0571	0.0571	0.0500	0.4381	0.0018	0.0021	0.0008	0.0007	0.0072	0.0007	0.0007	0.5500	
	0.4381	0.0018	0.0021	0.0008	0.0007	0.0072	0.0007	0.0007	0.0001	0.0712	0.1012	0.0524	0.0469	0.0641	0.0571	0.0571	0.0500	0.4359	0.0011	0.0009	0.0007	0.0073	0.0010	0.0010	0.0007	0.5500	
	0.4359	0.0011	0.0009	0.0007	0.0007	0.0073	0.0010	0.0007	0.0001	0.0712	0.1012	0.0524	0.0469	0.0641	0.0571	0.0571	0.0500	0.4133	0.0031	0.0082	0.0022	0.0028	0.0175	0.028	0.0500	0.0001	
Sensor 3:	0.6963	0.0003	0.0003	0.0028	0.0003	0.0003	0.0003	0.0003	0.0001	0.1626	0.1304	0.1463	0.1304	0.1304	0.1304	0.1304	0.1304	0.3000	0.6857	0.0009	0.0012	0.0110	0.0012	0.0012	0.0012	0.0012	0.3000
	0.6963	0.0003	0.0003	0.0028	0.0003	0.0003	0.0003	0.0003	0.0001	0.1626	0.1304	0.1463	0.1304	0.1304	0.1304	0.1304	0.1304	0.3000	0.6857	0.0009	0.0012	0.0110	0.0012	0.0012	0.0012	0.0012	0.3000
	0.6857	0.0009	0.0012	0.0110	0.0012	0.0012	0.0012	0.0012	0.0001	0.1626	0.1304	0.1463	0.1304	0.1304	0.1304	0.1304	0.1304	0.3000	0.6959	0.0033	0.0042	0.0285	0.0043	0.0300	0.0300	0.0300	0.3000
	0.6959	0.0033	0.0042	0.0285	0.0043	0.0300	0.0300	0.0300	0.0001	0.1626	0.1304	0.1463	0.1304	0.1304	0.1304	0.1304	0.1304	0.3000	0.4133	0.0031	0.0082	0.0022	0.0028	0.0175	0.028	0.0500	0.0001

Figure 3: Bba for the following target attributes: threat, platform and activity.

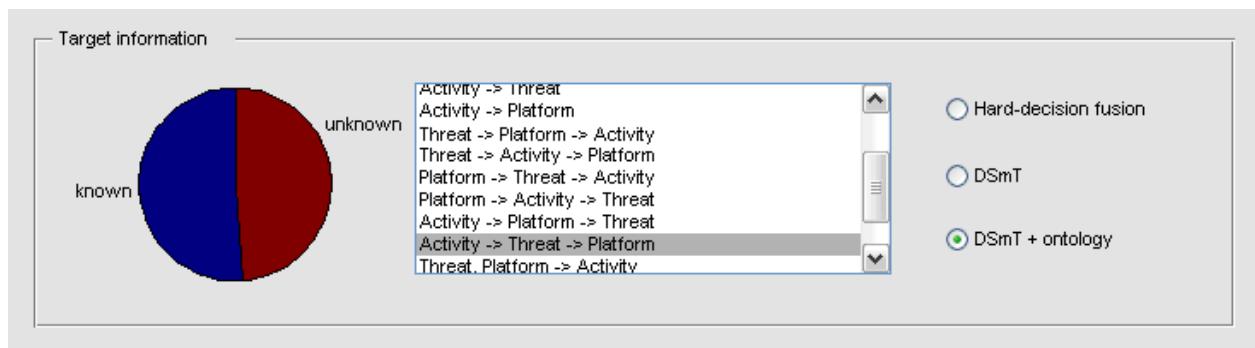
The main result of the sensor network is the decision about the target attributes made after taking into account both observations and reasoning. (see Figure 4).

<sup>4</sup> Search and Rescue.



**Figure 4: Final decision panel for: hard-decision fusion, DSmt and ontology DSmt respectively.**

In order to compare performances of considered fusion methods, a slice graph has been utilised to visualise a degree of knowledge about the target, acquired for each of the examined algorithms. The degree of knowledge has been defined based on the uncertainty of the hypothesis which had been selected as the final decision in decision-making process. (see Figure 5).



**Figure 5: Target info panel with a list of particular reasoning orders.**

In case of hard-decision fusion and *DSmt* fusion the uncertainty has been calculated as an average of the partial uncertainties (for each of the attributes).

In case of the ontology *DSmt* fusion the uncertainty has been calculated ‘intrinsically’ in conditioning process. The implemented ontology fuser also enables to compare the results for diverse attribute reasoning order, however the final decision is made upon the case of the lowest uncertainty.

## 8.0 EXAMINING OF ADVISIBLE SOLUTION

### 8.1 Numerical experiments

For the suggested sensor network a number of numerical experiments has been delivered with respect to:

- Random and
- Deterministic target trajectory;



There has been considered both:

- FRIEND and
- HOSTILE target attribute;

Fusion methods have been compared using diverse information sources:

- Video camera;
- Radar;
- Visual sightings;

The examination has been performed with various values of sensor reliability parameter and with number of sensors.

Sensor network parameters:

- Organisation:
  - Physical topology: N/A (simulation);
  - Logical topology: tree type;
  - Transmission medium: N/A;
- Information evaluation:
  - Threat attribute;
  - Platform attribute;
  - Activity attribute;
- Fusion methods/techniques:
  - Hard-decision fusion (*MR* implemented);
  - Soft-decision fusion (*DSmT*);
  - Ontology *DSmT* fusion;
- Ontology:
  - Lexicons: Link16, JC3, test lexicon for threat, platform and activity attributes respectively;
  - Relations have been defined using *Belief Conditioning Rule* no. 1 (*BCR1*);

## 8.2 Results of sensor network experiments

1. Examination of diverse sensors information fusion techniques for randomly generated target trajectory and target parameters:
  - Sensors: Visual sightings, video camera, radar;
  - Sensor reliability values:  $R_{VS} = 0.9$ ,  $R_{VC} = 0.8$ ,  $R_R = 0.7$ ;

**Table 3: Diverse sensors information fusion for randomly generated target trajectory**

<b>Attribute</b>	<b>Simulation</b>	<b>Hard-decision fusion</b>	<b>DSmT</b>	<b>DSmT + ontology</b>
<b>Threat</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FAKER</b>
<b>Platform</b>	<b>MHSD</b>	<b>MHS</b>	<b>MH</b>	<b>MHS</b>
<b>Activity</b>	<b>TRAINING</b>	<b>TRAINING</b>	<b>TRAINING</b>	<b>TRAINING</b>

2. Examination of diverse sensors information fusion techniques for randomly generated target trajectory and target parameters:

- Sensors: Visual sightings, video camera, radar;
- Sensor reliability values:  $R_{VS} = 0.9$ ,  $R_{VC} = 0.8$ ,  $R_R = 0.7$ ;

**Table 4: Diverse sensors information fusion for randomly generated target trajectory.**

<b>Attribute</b>	<b>Simulation</b>	<b>Hard-decision fusion</b>	<b>DSmT</b>	<b>DSmT + ontology</b>
<b>Threat</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FAKER</b>
<b>Platform</b>	<b>MHCD</b>	<b>MHCD</b>	<b>MH</b>	<b>MHC</b>
<b>Activity</b>	<b>TRAINING</b>	<b>TRAINING</b>	<b>TRAINING</b>	<b>TRAINING</b>

3. Examination of diverse sensors information fusion techniques for randomly generated target trajectory and target parameters:

- Sensors: Visual sightings, video camera, radar;
- Sensor reliability values:  $R_{VS} = 0.9$ ,  $R_{VC} = 0.8$ ,  $R_R = 0.7$ ;

**Table 5: Diverse sensors information fusion for randomly generated target trajectory.**

<b>Attribute</b>	<b>Simulation</b>	<b>Hard-decision fusion</b>	<b>DSmT</b>	<b>DSmT + ontology</b>
<b>Threat</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>
<b>Platform</b>	<b>MHCD</b>	<b>MHCD</b>	<b>MH</b>	<b>MHC</b>
<b>Activity</b>	<b>MINE</b>	<b>MINE</b>	<b>MINE</b>	<b>MINE</b>

4. Examination of diverse sensors information fusion techniques for randomly generated target trajectory and target parameters:

- Sensors: Visual sightings, video camera, radar;
- Sensor reliability values:  $R_{VS} = 0.9$ ,  $R_{VC} = 0.8$ ,  $R_R = 0.7$ ;

**Table 6: Diverse sensors information fusion for randomly generated target trajectory.**

<b>Attribute</b>	<b>Simulation</b>	<b>Hard-decision fusion</b>	<b>DSmT</b>	<b>DSmT + ontology</b>
<b>Threat</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>
<b>Platform</b>	<b>MHSO</b>	<b>MHSO</b>	<b>MH</b>	<b>MHO</b>
<b>Activity</b>	<b>MINE</b>	<b>MINE</b>	<b>MINE</b>	<b>MINE</b>

5. Examination of diverse sensors information fusion techniques for randomly generated target trajectory and target parameters:

- Sensors: Visual sightings, video camera, radar;
- Sensor reliability values:  $R_{VS} = 0.9$ ,  $R_{VC} = 0.8$ ,  $R_R = 0.7$ ;



**Table 7: Diverse sensors information fusion for randomly generated target trajectory.**

Attribute	Simulation	Hard-decision fusion	DSmT	DSmT + ontology
<b>Threat</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>
<b>Platform</b>	<b>MHSO</b>	<b>MHSO</b>	<b>MH</b>	<b>MHSO</b>
<b>Activity</b>	<b>UNKNOWN</b>	<b>UNKNOWN</b>	<b>MINS</b>	<b>MINS</b>

6. Examination of diverse sensors information fusion techniques for randomly generated target trajectory and target parameters:

- Sensors: Video camera, radar;
- Sensor reliability values:  $R_{VC} = 0.55$ ,  $R_R = 0.55$ ;

**Table 8: Diverse sensors information fusion for randomly generated target trajectory.**

Attribute	Simulation	Hard-decision fusion	DSmT	DSmT + ontology
<b>Threat</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>
<b>Platform</b>	<b>MHCD</b>	<b>MH</b>	<b>MH</b>	<b>MHI</b>
<b>Activity</b>	<b>MINE</b>	<b>MINS</b>	<b>MINH</b>	<b>MINH</b>

7. Examination of diverse sensors information fusion techniques for deterministically generated target trajectory and target parameters:

- Sensors: Visual sightings, video camera, radar;
- Sensor reliability values:  $R_{VS} = 0.9$ ,  $R_{VC} = 0.8$ ,  $R_R = 0.7$ ;
- Sensors positions (in Cartesian coordinate system XY):
- $P_{VS} = [6.1, 10.5]$ ,  $P_{VC} = [9.1, 12.5]$ ,  $P_R = [5.1, 10.5]$ ;
- Starting point of the deterministic target trajectory:  $[4.0, 14.0] \rightarrow$  ‘convenient’ observation conditions.

**Table 9: Diverse sensors information fusion for deterministically generated target trajectory.**

Attribute	Simulation	Hard-decision fusion	DSmT	DSmT + ontology
<b>Threat</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>
<b>Platform</b>	<b>MHCD</b>	<b>MHCD</b>	<b>MH</b>	<b>MHC</b>
<b>Activity</b>	<b>MINE</b>	<b>MINE</b>	<b>MINE</b>	<b>MINE</b>

8. Examination of diverse sensors information fusion techniques for deterministically generated target trajectory and target parameters:

- Sensors: Visual sightings, video camera, radar;
- Sensor reliability values:  $R_{VS} = 0.9$ ,  $R_{VC} = 0.8$ ,  $R_R = 0.7$ ;
- Sensors positions (in Cartesian coordinate system XY):
- $P_{VS} = [6.1, 10.5]$ ,  $P_{VC} = [9.1, 12.5]$ ,  $P_R = [5.1, 10.5]$ ;
- Starting point of the deterministic target trajectory:  $[4.0, 19.0] \rightarrow$  ‘inconvenient’ observation conditions.

**Table 10: Diverse sensors information fusion for deterministically generated target trajectory.**

<b>Attribute</b>	<b>Simulation</b>	<b>Hard-decision fusion</b>	<b>DSmT</b>	<b>DSmT + ontology</b>
<b>Threat</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>
<b>Platform</b>	<b>MHCD</b>	<b>MH</b>	<b>MH</b>	<b>MHC</b>
<b>Activity</b>	<b>MINE</b>	<b>MINE/MINS</b>	<b>MINE</b>	<b>MINE</b>

9. Examination of diverse sensors information fusion techniques for deterministically generated target trajectory and target parameters:
- Sensors: Visual sightings, video camera, radar;
  - Sensor reliability values:  $R_{Vs} = 0.9$ ,  $R_{Vc} = 0.8$ ,  $R_R = 0.7$ ;
  - Sensor positions (in Cartesian coordinate system XY):
  - $P_{Vs} = [6.1, 10.5]$ ,  $P_{Vc} = [9.1, 12.5]$ ,  $P_R = [5.1, 10.5]$ ;
  - Starting point of the deterministic target trajectory:  $[7.0, 20.0] \rightarrow$  ‘inconvenient’ observation conditions.

**Table 11: Diverse sensors information fusion for deterministically generated target trajectory.**

<b>Attribute</b>	<b>Simulation</b>	<b>Hard-decision fusion</b>	<b>DSmT</b>	<b>DSmT + ontology</b>
<b>Threat</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>	<b>FRIEND</b>
<b>Platform</b>	<b>MHCD</b>	<b>MH</b>	<b>MH</b>	<b>MHC</b>
<b>Activity</b>	<b>MINE</b>	<b>MINS</b>	<b>MINE</b>	<b>MINE</b>

## 8.2 Examination summary

In case the number of sensor rises the hard-decision fusion delivers better results than other methods. That is in accordance to the expectations, since this method introduces relatively low rate of uncertainty. *DSmT* fusion provides more ‘general’ solution. However it is important to notice that the considered methods are not equipped with the same mechanism of the evaluation of knowledge about the target. Although it is reasonable to assume that both *DSmT*-based methods have the identical mechanisms, in case of the hard-decision fusion the degree of knowledge about the target is calculated due to the formula (1), which strongly reduces the uncertainty of the final decision. It is possible to observe that even if the number of sensor is two. In considered cases the hard-decision fusion offers more precise solution comparing to the rest of the considered techniques, however the risk of wrong decision is also relatively bigger due to the exclusive nature of this technique.

It is also worth of notice that during experimentations all of the techniques have been supplied with information originated from *the evaluator*, which is quite unusual for the hard-decision fusion. It is expectable that in typical application, this technique would provide a higher rate of wrong decisions.

Based on the numerical experiments it is easy to notice that the ontology *DSmT* provides satisfactory results. Due to the *DSmT* engine the decision is ‘secure’ - that is adequate to the simulation, however not very precise. The ontology, on the other hand, enables to ‘home’ the reasoning process, which results in increased precision of the final decision.



## 9.0 CONCLUSIONS

The concept and numerical experiments presented in this paper have given some viewpoint, related to an application of *DSmT* in C&C systems. They also have provided some basic verification of the effectiveness of *DSmT*-based fusion techniques, showing their advantages like ‘security’ and ‘adequacy’ of the elaborated decisions, and disadvantages like relatively low precision of the final decision.

The synergy of two approaches: *DSmT* and ontology, presented in this paper, seems to have good prospects for the future application in real C&C systems. However, it requires some further examination, particularly related to specification of hybrid *DSm* models, and also selection of combination and conditioning rules.

## 10.0 REFERENCES

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